Understanding the large pT spectrum in SIDIS

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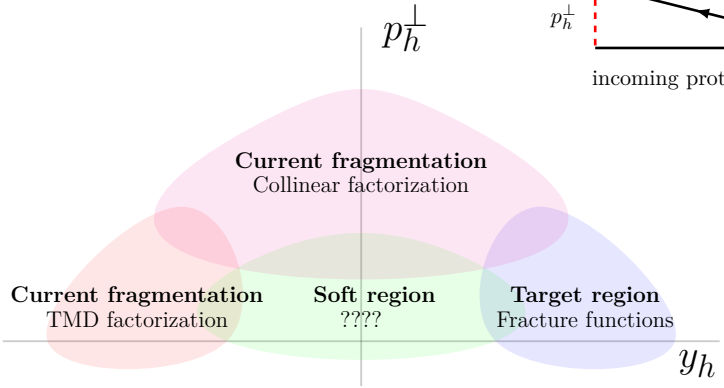
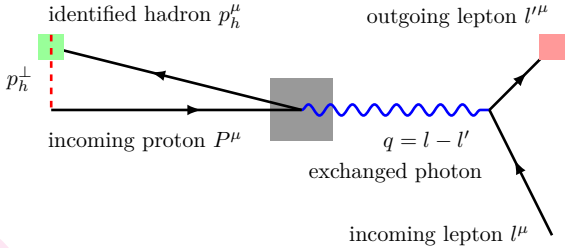
In collaboration with:
Gonzalez-Hernandez, Rogers, NS, Wang

- PRD98 **2018**
- arXiv:1903.01529 **2019**

SIDIS regions

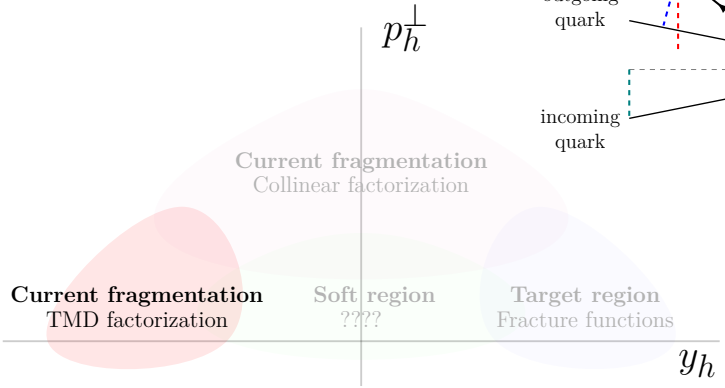


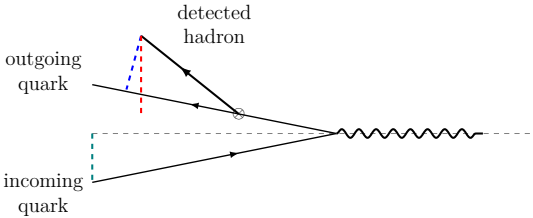
Breit frame



SIDIS regions

small transverse momentum

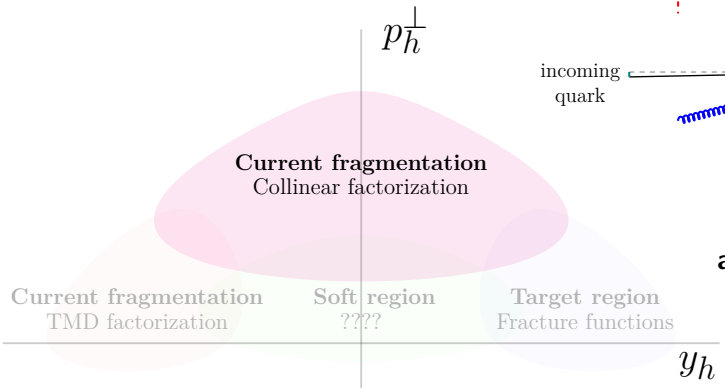


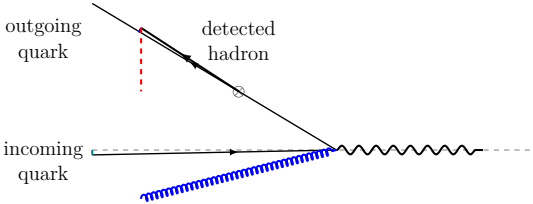


aka W

SIDIS regions

large transverse momentum



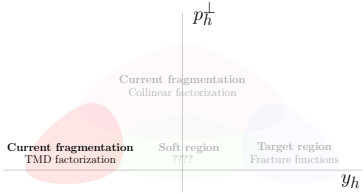


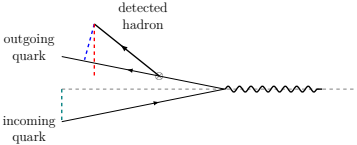
aka FO (=fixed order)

SIDIS regions

small transverse momentum

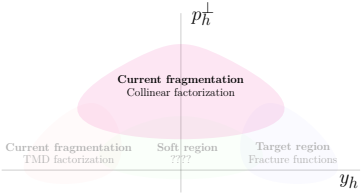
W

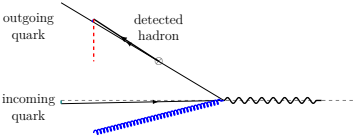




large transverse momentum

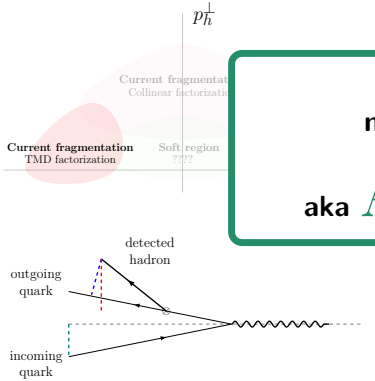
FO



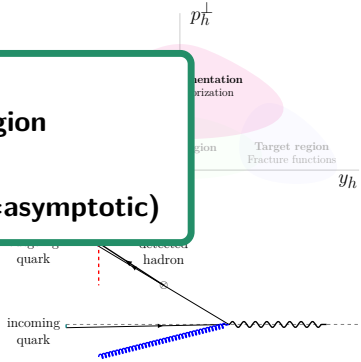


SIDIS regions

small transverse momentum W



large transverse momentum FO



matching region

aka ASY **(=asymptotic)**

SIDIS regions

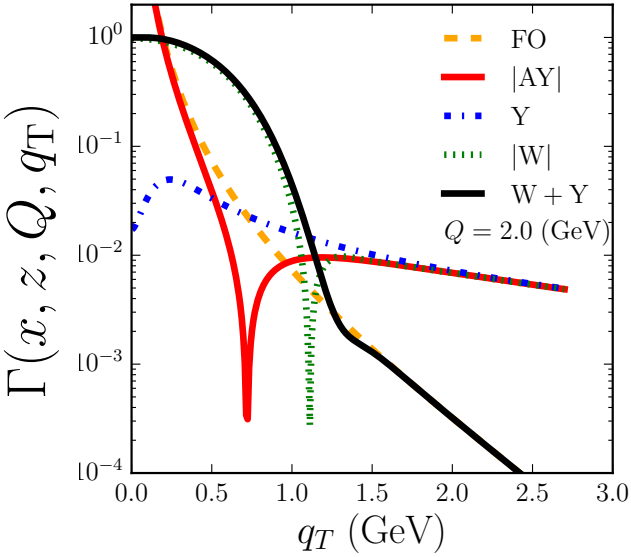
$$\frac{d\sigma}{dx dQ^2 dz dp_h^\perp} = \mathrm{W} + \mathrm{FO} - \mathrm{ASY} + \mathcal{O}(m^2/Q^2)$$

$$\sim \mathrm{W} \quad \text{for } q_\mathrm{T} \ll Q$$

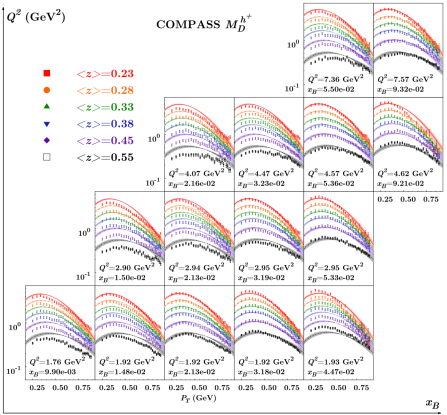
$$\sim \mathrm{FO} \quad \text{for } q_\mathrm{T} \sim Q$$

$q_\mathrm{T}/Q = (p_h^\perp/z)/Q \rightarrow$ scale separation

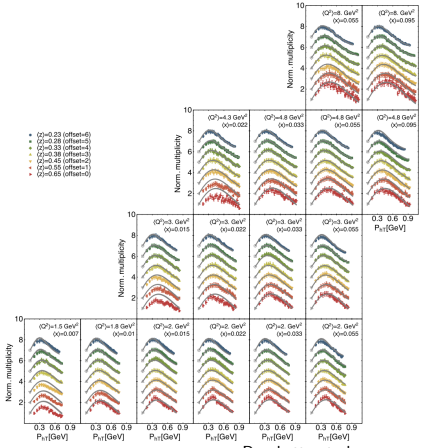
Toy example


FO
|AY|
Y
|W|
W + Y
$Q = 2.0$ (GeV)
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0.0
0.5
1.0
1.5
2.0
2.5
3.0
$\Gamma(x, z, Q, q_T)$
q_T (GeV)

Existing phenomenology



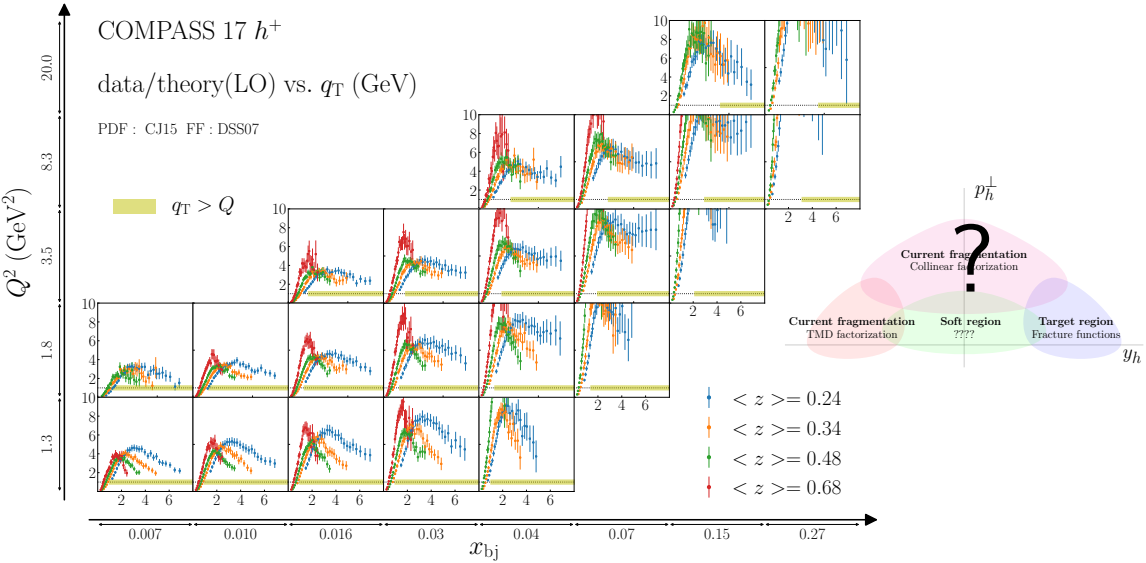
Anselmino et al



Bacchetta et al

- These analyses used only W (Gaussian, CSS) → no FO nor ASY
- Samples with $q_T/Q \sim 1.63$ have been included
- **BUT TMDs are only valid for $q_T/Q \ll 1$!**

FO @ LO predictions (DSS07) Gonzalez, Rogers, NS, Wang PRD98 (2018)

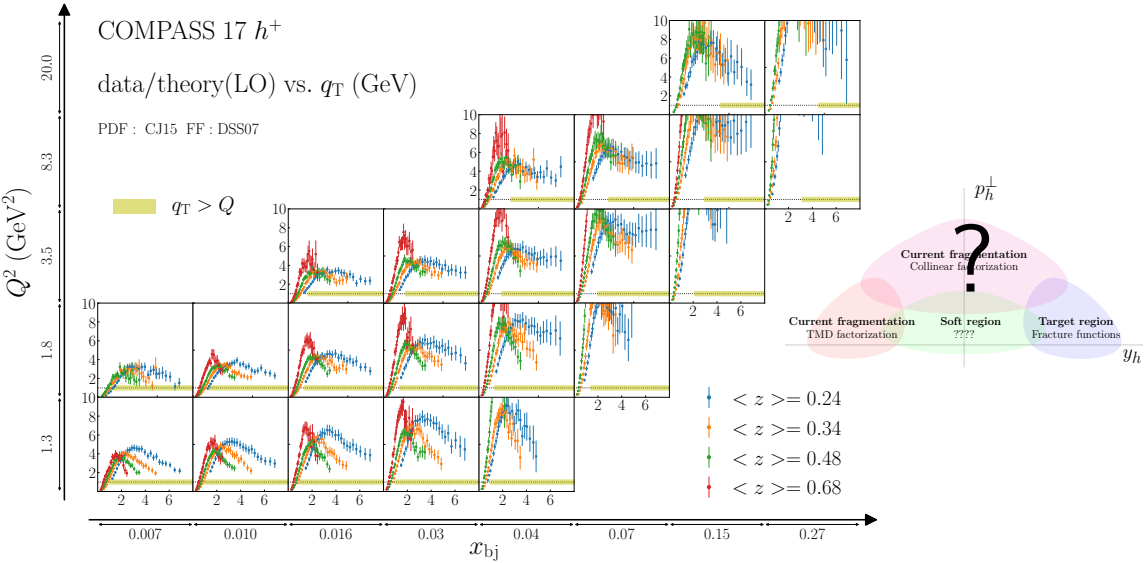


Trouble with large transverse momentum

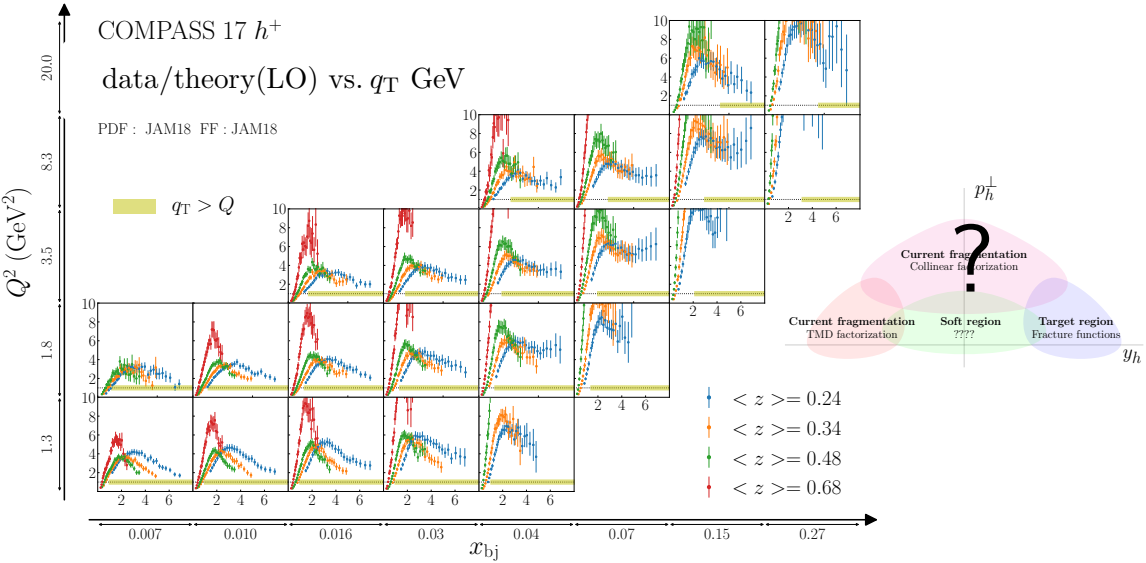
$$\mathrm{FO} = \sum_q e_q^2 \int_{\frac{q_T^2}{Q^2}\frac{xz}{1-z}+x}^{1} \frac{d\xi}{\xi - x}\, H(\xi)\, \boldsymbol{f}_q(\xi,\mu)\, \boldsymbol{d}_q(\zeta(\xi),\mu) + O(\alpha_S^2) + O(m^2/q^2)$$

+ FFs needs to be updated?

FO @ LO predictions (DSS07) Gonzalez, Rogers, NS, Wang PRD98 (2018)



FO @ LO predictions (JAM18) Gonzalez, Rogers, NS, Wang PRD98 (2018)



Trouble with large transverse momentum

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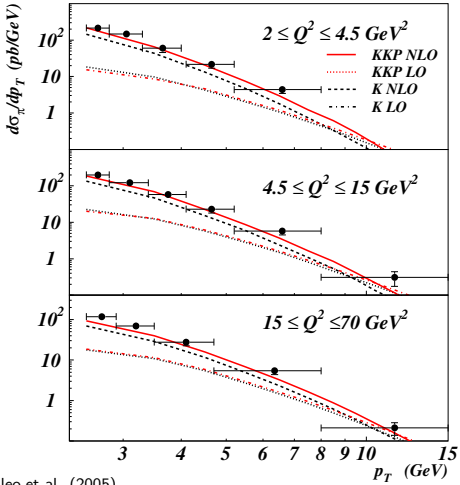
$+\ O(\alpha_S^2)$ corrections might be important

order α_S^2 corrections to FO



Daleo,et al. (2005)
PRD.71.034013

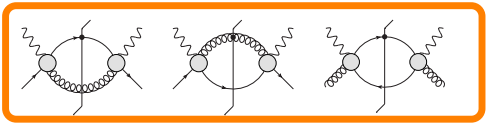
- There are strong indications that order α_S^2 corrections are very important
- An order of magnitude correction at small p_T.
- As a sanity check, we need to have an independent calculation

$O(\alpha_S^2)$ calculation (Wang, Gonzalez-Hernandes, Rogers, NS - arXiv:1903.01529)

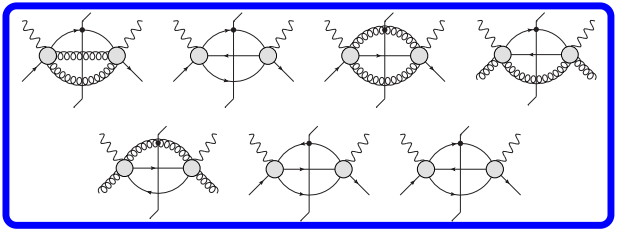
$$W^{\mu\nu}(P,q,P_H) = \int_{x-}^{1+} \frac{d\xi}{\xi} \int_{z-}^{1+} \frac{d\zeta}{\zeta^2} \hat{W}_{ij}^{\mu\nu}(q, x/\xi, z/\zeta) f_{i/P}(\xi) d_{H/j}(\zeta)$$

$$\{\mathrm{P}_g^{\mu\nu}\hat{W}_{\mu\nu}^{(N)}; \mathrm{P}_{PP}^{\mu\nu}\hat{W}_{\mu\nu}^{(N)}\} \equiv \frac{1}{(2\pi)^4} \int \{|M_g^{2\to N}|^2; |M_{pp}^{2\to N}|^2\} \, \mathrm{d}\Pi^{(N)} - \text{Subtractions}$$

Born/Virtual

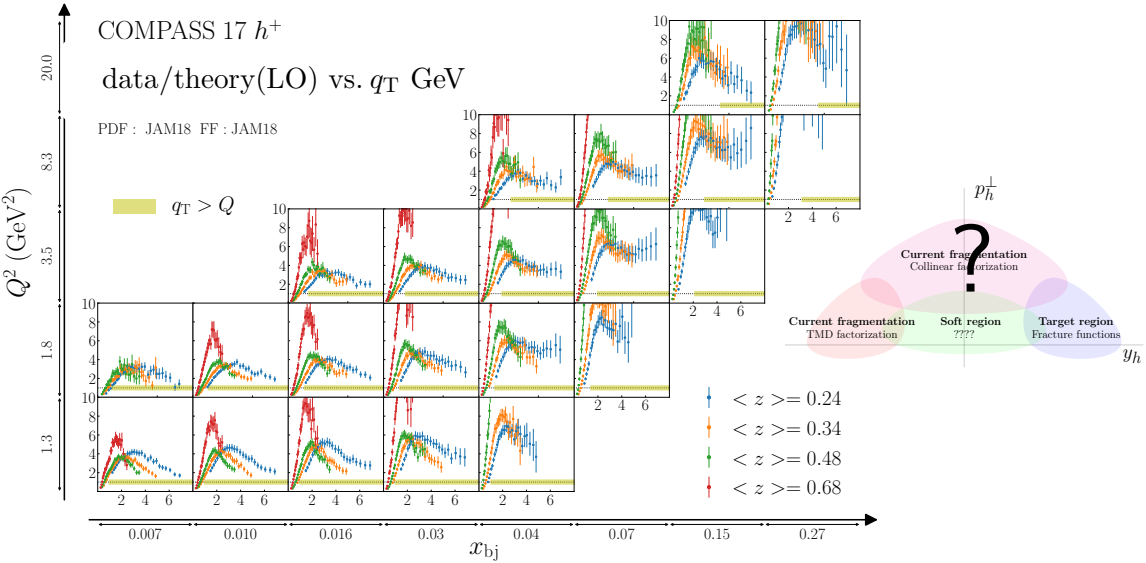


Real

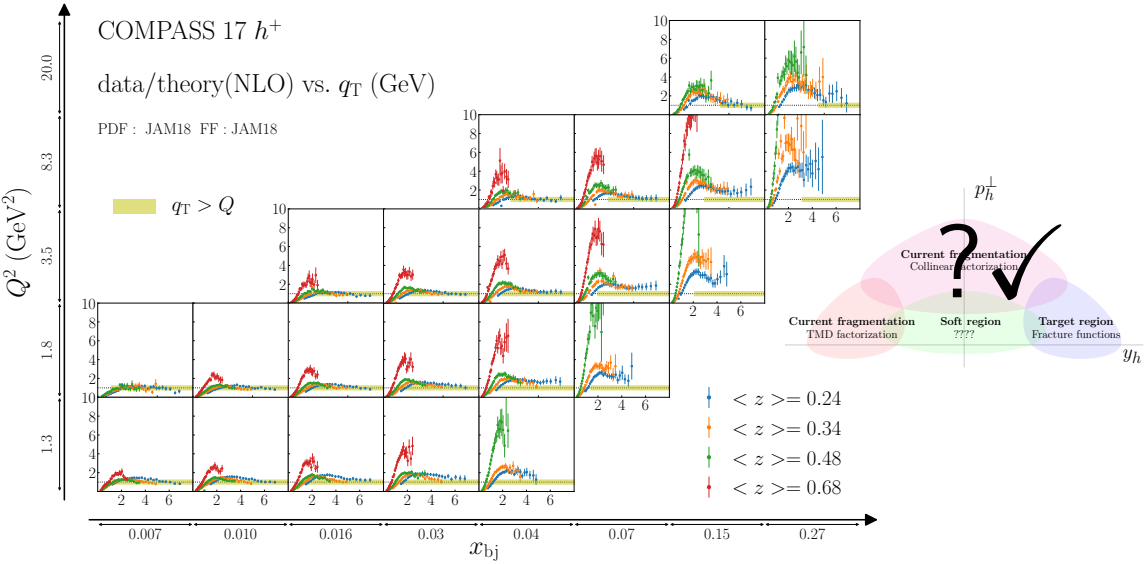


- ✓ Generate all $2 \to 2$ and $2 \to 3$ squared amplitudes
- ✓ Evaluate $2 \to 2$ virtual graphs (Passarino-Veltman)
- ✓ Integrate 3-body PS analytically
- ✓ Check cancellation of IR poles

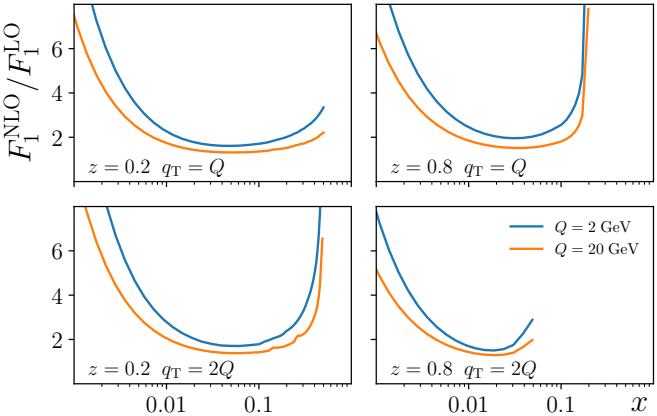
FO @ LO predictions (JAM18)



FO @ NLO (JAM18)


COMPASS 17 h^+
data/theory(NLO) vs. q_T (GeV)
PDF : JAM18 FF : JAM18
$q_T > Q$
Q^2 (GeV^2)
20.0
8.3
3.5
1.8
1.3
0.007
0.010
0.016
0.03
0.04
0.07
0.15
0.27
x_{bj}
$< z >= 0.24$
$< z >= 0.34$
$< z >= 0.48$
$< z >= 0.68$
$p_h^\perp$
y_h
Current fragmentation
Collinear factorization
Current fragmentation
TMD factorization
Soft region
????
Target region
Fracture functions

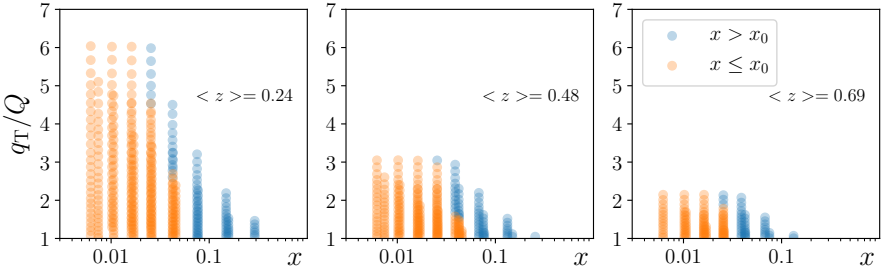
Understanding the large x (Wang, Gonzalez-Hernandes, Rogers, NS - arXiv:1903.01529)



- Large corrections threshold corrections are observed
- The x at the minimum can be used as an indicator of where such corrections are expected to be large

Understanding the large x (Wang, Gonzalez-Hernandes, Rogers, NS - arXiv:1903.01529)

COMPASS kinematics



- The blue region might receive large threshold corrections
- This can potential explain why the $O(\alpha_S^2)$ fail to describe the data at large x

Summary and outlook

- $O(\alpha_S^2)$ corrections are important to describe SIDIS at COMPASS
- The large x region receives large threshold corrections which can explain the difficulty to describe the data
- Potential impact of SIDIS large p_T data on PDFs/FFs global analysis